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JOURNAL OF THE INSTITUTE OF PETROLEUM

FOUNDED 1913 INCORPORATED 1914

Vol. 28 NOVEMBER 1942 No. 227

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Published by the Institute of Petroleum.
Address: c/o The Imperial College of Science and Technology, South Kensington, London, S.W.7.
Printed in Great Britain by Richard Clay and Company, Ltd., Bungay, Suffolk.

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VOL. 28. No. 227. NOVEMBER 1942.

FLOW OF LIQUIDS UNDER CRITICAL CONDITIONS.

By Dr. A. H. NISSAN.

INTRODUCTION.

MUCH research has been done on the flow of liquids and gases through tubes under different conditions. For Newtonian fluids the laws governing viscous flow through tubes of uniform cross-sections are well founded on both theoretical and experimental grounds. Whilst not so well understood, the turbulent regime for these systems is fairly capable of determination provided certain implicit assumptions in the theory of dimensions are rigidly justified, particularly the principle of geometrical similarity. The intermediate state existing between the two regimes, the critical state, is still a field of contradiction. In the present work this field was particularly studied, and certain significant details are now reported.

THEORY.

D'Arcy's formula for full flow in enclosed boundaries is

$$H = f\frac{1}{m}\frac{\rho v^2}{2g}$$

where H = head lost over distance l
m = hydraulic mean depth
v = mean velocity of flow
ρ = density of fluid
f = a pure number

For a straight tube having circular cross-section $m = d/4$ and using water at low temperatures the difference in ρ from unity is negligible.

Substituting for "m" and rearranging,

$$\frac{f}{2} = \frac{H}{1}\cdot\frac{d}{4}\cdot\frac{g}{v^2}$$

$$v = \frac{Q_t}{A} = \frac{4Q_t}{\pi d^2}$$

where Q_t = volume per sec.

$$\frac{f}{2} = \frac{H}{1}\cdot\frac{d}{4}\cdot\frac{g\pi^2 d^4}{16Q_t^2}$$

$$= \frac{H}{Q_t^2}\frac{(\pi^2 g d^5)}{6-1}$$

i.e., $$\frac{f}{2} \propto \frac{H}{Q_t^2}$$ for a single pipe.

Also,

$$\text{Reynolds Number} = \frac{vd\rho}{\mu} = \frac{vd}{\nu} = \frac{\frac{4Qt}{\pi d^2}d}{\nu} = \frac{Q_t}{\nu}\left(\frac{4}{\pi d}\right)$$

where ν = kinematic viscosity

i.e., $$R_e \propto \frac{Q_t}{\nu}$$

where R_e = Reynolds Number.

It is known that $f/2 = \phi(R_e)$, *i.e.*, a plot of the friction factor f against corresponding values of Reynolds numbers gives a smooth curve. In the viscous state a plot of $\log f/2$ *vs.* $\log R_e$ yields a straight line as

$$\frac{f}{2} = \frac{8}{R_e}$$

For other regimes different curves are obtained for different pipes, depending on their degrees of roughness.

Fig. 1 is a reproduction of the figure given by Beale and Docksey [1] in the *Science of Petroleum*, and illustrates the type of curves obtained. It will be seen that the smaller the inner diameter of the pipe the rougher it appears to be—*i.e.*, the higher the value of $f/2$ (k on the figure) for the same value of Reynolds number.

It is to be noted that the change-over from the streamline or viscous curve to the turbulent curve is not accepted by all authorities to be the smooth curves shown. The value of $f/2$ in the critical region is sometimes obtained by extrapolating the turbulent curve backward. In other cases it is advocated that the curves shown should be used. It is the purpose of this work to investigate which of the two proposed methods is to be employed in regions characterized by Reynolds numbers ranging between 1000 and 4000. Only water was used in conjunction with a single pipe, as it is already known that for flow of fluids in pipes what is true of one pipe is true of others.

Apparatus.

The apparatus finally used is shown in Fig. 2. In a previous form only one constant-level device was used at the inlet.

While taking observations of the head during flow in the critical and to a lesser extent in the turbulent regions, it was found that there was a continual oscillation in the level of the exit manometer, increasing with the head of water. It was further observed that the inlet manometer oscillated also roughly in time with the exit oscillation, but the oscillation in the inlet was of much smaller magnitude. As it was uncertain whether the exit oscillation was induced by inlet irregularities or by the turbulence within the tube, it was decided to eliminate any inlet variations of head as completely as possible. Since it was not possible to do this with the single constant-head device, a new one was designed. It was further considered that surface irregularities in the long length of rubber connecting-hose may have induced a varying pressure drop at the end, and consequently in the modified apparatus it was replaced by a large-diameter glass tube of uniform smoothness. The water flowed into the

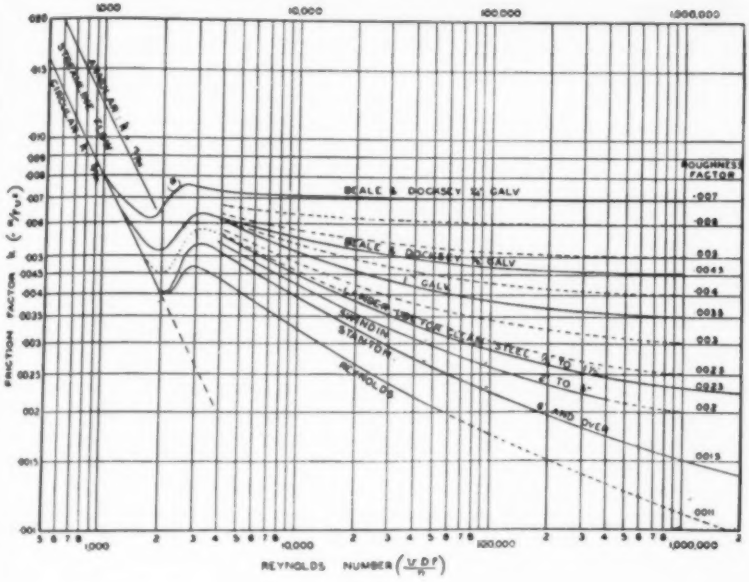
1000
10,000
100,000
1,000,000
ROUGHNESS FACTOR
·007
·008
·009
·0045
·004
·0035
·003
·0025
·002
·0015
·001
BEALE & DIGGSBY ¼" GALV
BEALE & DIGGSBY ½" GALV
1" GALV
SMOOTH PIPES
SUDRON STANTON
REYNOLDS
FRICTION FACTOR h (g D/v²)
REYNOLDS NUMBER (V D ρ / η)

FIG. 1.

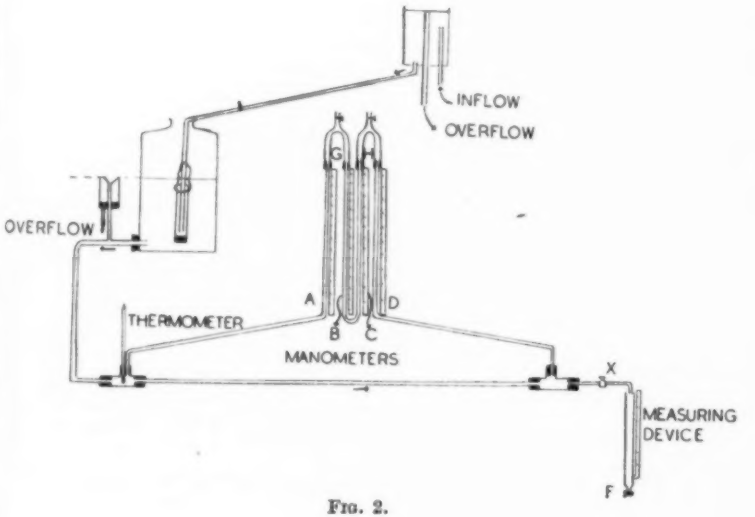
INFLOW
OVERFLOW
OVERFLOW
G
H
A
D
B
C
THERMOMETER
MANOMETERS
X
MEASURING DEVICE
F

FIG. 2.

large-diameter constant-level device fom a smaller constant-level device and, further, lost any tendency for shock by changing direction through 180°, as shown in the sketch.

The level of the water in the large bottle was arranged, initially, to be just below the top of the water manometer, so that the whole range of this manometer could be covered by the one position of the apparatus. The bottle was then raised several feet and re-connected by means of wide glass tubing, and further readings were taken on the mercury manometer. It was observed that while the inlet head remained appreciably constant, there was still slight oscillation in the exit pressure when flow was in the critical region. The head was steady both in the viscous and turbulent regions, but, in spite of all precautions, could not be maintained exactly so in the critical region. Manometric tubes *A* and *D* were used as water manometers. Tubes *B* and *C* contained mercury in their lower halves and water from *A* and *D* in the top. The central mercury manometer was employed for differences in head greater than 90 cm. of water. It was brought into operation on closing the two top taps above *G* and *H* after filling with water to a level above the taps. Initially care was taken to ensure that the board containing the manometers and scales was set excatly vertical in both planes. A small correction to be applied to the scale readings due to the scale zeros not corresponding was obtained by reading the liquid heights in each limb when no flow was taking place.

Since the accuracy in determining the quantity of water flowing had necessarily to be high, the device shown in the sketch was constructed. The small-diameter vertical side tube was calibrated to show 100, 250, and 500 c.c., and was fitted in order to eliminate errors due to eddies and surges, thus enhancing the accuracy. The time taken to fill various volumes was measured by a stop-watch. For the highest heads a 2000-c.c. flask was used.

Before any readings were taken all air was driven from the apparatus by passing water under a large head through the tube. Tap *X* was closed until water overflowed from *A* and *D* to fill *B* and *C*. Small bubbles remaining in the rubber connections were removed by raising and lowering the tubing.

In setting up, the manometer tubes were carefully cleaned, and filtered mercury used, to avoid air bubbles sticking to the tubes, and to eliminate viscous drag of the water meniscus on a dirty patch. Tap *X* was then opened, and the head reduced to the smallest obtainable. When the manometer had steadied, the time taken for a given quantity of water to flow through the tube was taken by closing tap *F* and a stop-watch started as the fluid level passed the zero marking. The watch was stopped as the fluid level passed the required mark. The head readings on *A* and *D* were taken and the water temperature was noted. The head was increased progressively by either opening tap *X* a little more or by raising the reservoir. When the limit of the water manometer had been reached, the head was increased until water filled tubes *G* and *H*, when the top taps were closed. The readings were then continued as before, but now the heads were read on scales *B* and *C*.

It will be apparent from the equation derived that the diameter of the tube is all-important, since its value is raised to the fifth power. Hence,

special care was taken in determining its value. The tube was of copper, cold drawn, with inside diameter assumed uniform over considerable lengths. The methods used were as follows :

Method 1.

A section of tube about 17 cm. long was cleaned, dried, and its length measured. It was then filled with mercury with tapping, etc., to remove trapped air.

The mercury was run into a tared beaker, and from its density at room temperature, the diameter was computed.

Length = 16·79 cm.
Wt. of mercury 30·14079, 30·02377, 30·09685 } Mean 30·08714
Density of Hg at 20° C. = 13·5462
Diameter = 0·410 cm.

Method 2.

The section of tube was placed under a Brinnel microscope and a number of direct measurements were obtained. It was apparent from the readings that the cross-section was by no means uniform, due probably to the cutting of the soft tube. No completely satisfactory estimate of the diameter could be made.

$$d = 0{\cdot}405 \text{ cm.}$$

Method 3.

A metal plug was turned so as to fit exactly inside the tube. The plug diameter was determined by micrometer.

$$d = 0{\cdot}410 \text{ cm.}$$

The value of diameter finally selected was 0·410, being that obtained by methods 1 and 3, giving the most consistent and satisfactory results. This value was checked hydrodynamically, as will be shown below, and found to be sufficiently accurate.

Length.

Three operators were asked to make independent determinations of the tube length with a metre rule. All agreed on 190·3 cm., which value was accepted.

Results.

Flow in the viscous regime affords an easy and useful check on the measurements of the various constants of the apparatus, as well as a near-absolute method of determining the accuracy and precision of the technique employed. It is to be noted that there will be pressure losses in the apparatus due to change of sections both at inlet and outlet of the

apparatus. This means that the head registered by the manometer will be too high. For sudden enlargement, the number of velocity heads to be allowed is equal to $(1 - b)^2$, and for sudden contraction is $0{\cdot}5(1 - b)$,

where
$$b = \frac{\text{area of flow pipe}}{\text{area of T piece}}$$
$$= \frac{(0{\cdot}41)^2}{(\frac{11}{16} \times 2{\cdot}54)^2} = 0{\cdot}0296$$

Number of velocity heads for enlargement $= 0{\cdot}942$
" " " " " contraction $= 0{\cdot}485$

$1{\cdot}43$

$$\text{Loss in pressure} = 1{\cdot}43 \times \frac{\rho v^2}{2g}$$
$$= \frac{1{\cdot}43}{2 \times 981} \times \frac{(4Q_t)^2}{\pi d^2}$$
$$= 0{\cdot}0418\, Q_t^2 \text{ cm. of water.}$$

This factor is subtracted from the experimental head to give the true pressure head lost in the pipe due to friction.

Thus three runs in the viscous region were made, with a period of several weeks lapsing between each, to test the method and technique. Table I gives the results.

TABLE I.

No.	H, cm. of water.	Q_t, c.c./sec.	t, ° C.	ν, stokes.	Corrn. to $H = 0{\cdot}0418\, Q_t^2$.	H corrd., cm. of water.	$f/2 \times 10^3$.	R_c.
				Run 1.				
1	3·89	1·111	9·35	0·01333	0·03	3·86	28·8	259
2	7·60	2·065	9·35	0·01333	0·11	7·49	16·2	481
3	13·63	3·400	9·35	0·01333	0·29	13·34	10·63	792
4	16·11	4·170	9·36	0·01333	0·43	15·68	8·31	971
				Run 2.				
1	4·86	1·115	4·6	0·015383	0·03	4·83	35·4	226
2	5·53	1·276	4·5	0·015432	0·04	5·49	31·09	258
3	7·44	1·740	4·7	0·015334	0·08	7·36	22·39	352
4	8·90	2·060	4·8	0·015286	0·11	8·79	19·06	419
5	9·41	2·143	4·9	0·015238	0·11	9·30	18·62	437
6	12·39	2·818	5·0	0·015189	0·20	12·19	14·15	576
7	13·90	3·19	5·2	0·015097	0·25	13·65	12·23	627
8	16·94	3·87	5·7	0·014867	0·37	16·57	10·23	809
9	21·16	4·80	5·9	0·014775	0·57	20·59	8·23	1009
				Run 3.				
1	3·01	0·933	12·14	0·012322	0·02	2·99	30·06	238
2	4·11	1·144	12·10	0·012336	0·03	4·09	28·18	291
3	5·91	1·613	12·05	0·012352	0·07	5·84	20·18	406
4	7·70	2·045	12·00	0·012369	0·11	7·60	16·60	514
5	9·51	2·57	12·00	0·012369	0·17	9·34	12·82	649
6	14·1	3·56	12·00	0·012369	0·32	13·8	9·44	897

Fig. 3 shows the plot of log $(f/2)$ *vs.* log (R_e) for the three runs.

It will be seen that except for a determination on the first run and another at the beginning of the third run, the points lie fairly accurately on the theoretical line $\frac{f}{2} = \frac{8}{R_e}$. Thus the constants of the apparatus and

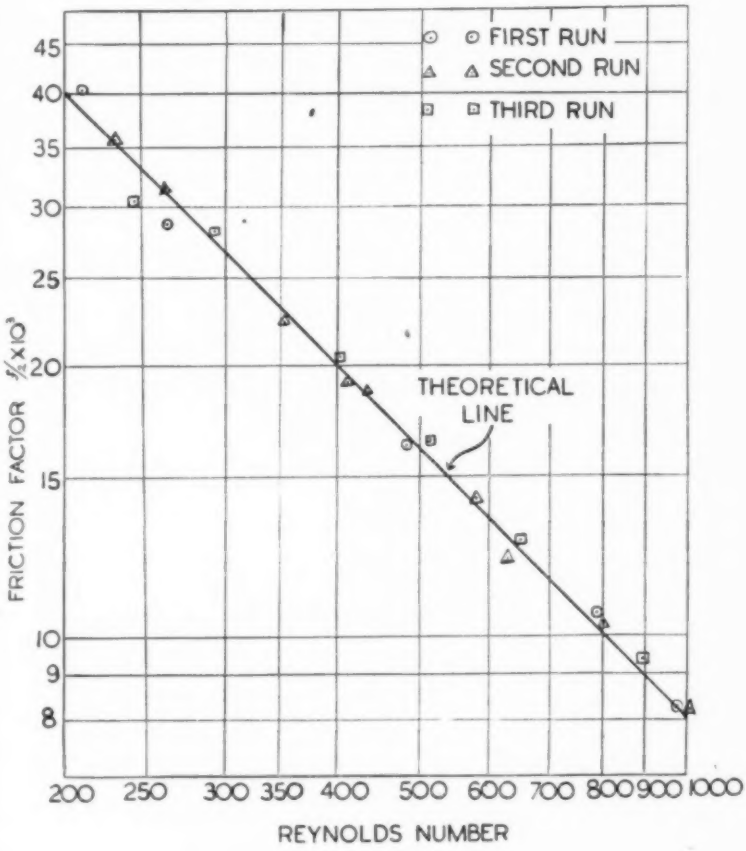

FIG. 3.

the corrections used in the calculations are justified within the degree of accuracy required for engineering data.

The critical regime in the system was investigated by running two series of experiments concentrating on the flow occurring between 2000 and 3000 Reynolds numbers. For continuity, however, both lower and higher values were used, so that a clear connection between the viscous and turbulent states might be evident. Table II gives the results of the runs.

Fig. 4 shows a plot of the friction factor *vs.* the corresponding Reynolds numbers for the critical region. It can be seen from the figure that :

(1) In spite of all the precautions taken to exclude external sources of turbulence, there is an appreciable deviation from the viscous line at all values exceeding 1000 Reynolds numbers. It is shown below that for values of R_e ranging between 1000 and 2100 this divergence is not accentuated by external sources of turbulence.

TABLE II.

No.	H, cm. of water.	Q_t, c.c./sec.	t, ° C.	ν, centistokes.	Corrn. to H, $= 0{\cdot}0418\,Q_t^2$.	H corrd., cm. of water.	$f/2\times10^3$.	R_e.
1	19·1	4·71	12·05	1·2352	0·6	18·5	7·36	1194
2	23·8	5·59	12·05	1·2352	0·7	23·1	6·79	1406
3	29·3	6·76	12·40	1·2236	1·2	28·2	5·50	1718
4	34·3	7·64	12·45	1·2219	1·4	32·9	5·00	1945
5	38·7	8·23	12·55	1·2186	1·7	37·0	4·81	2113
6	40·8	8·48	12·45	1·2219	1·8	39·0	4·69	2178
7	43·2	8·74	12·40	1·2236	1·9	41·3	4·68	2249
8	46·2	8·90	12·35	1·2252	2·0	44·2	4·92	2280
9	50·3	8·93	13·2	1·1172	2·0	48·3	5·47	2500
10	53·6	9·09	13·2	1·1172	2·1	51·5	5·50	2547
11	56·9	9·25	13·1	1·2004	2·2	54·7	5·65	2430
12	60·0	9·45	13·0	1·2036	2·3	57·7	5·66	2472
13	63·5	9·63	12·9	1·2069	2·4	61·1	5·81	2512
14	66·9	9·81	12·8	1·2103	2·5	64·4	5·81	2559
15	69·7	9·94	12·7	1·2136	2·5	67·2	6·08	2570
16	70·8	10·02	12·4	1·2236	2·6	68·2	6·00	2588
17	74·3	10·22	12·2	1·2302	2·6	71·7	6·05	2618
18	78·0	10·37	12·2	1·2302	2·8	75·2	6·04	2636
19	80·7	10·55	12·1	1·2336	2·8	77·9	6·12	2679
20	84·1	10·65	12·0	1·2369	2·9	81·2	6·37	2704
21	87·7	10·97	11·9	1·2404	3·1	84·6	6·17	2799
22	89·9	11·10	11·9	1·2404	3·1	86·8	6·17	2812
1	29·6	7·28	17·75	1·0626	2·2	27·4	4·96	2148
2	75·5	9·94	18·10	1·0533	4·0	71·5	6·43	2951
3	113·9	12·38	18·15	1·0520	6·2	107·7	6·34	3648
4	149·6	13·74	18·25	1·0494	7·7	141·9	6·78	4093
5	155·1	14·70	18·35	1·0468	8·9	146·2	6·12	4345
6	163·3	15·06	18·70	1·0377	9·3	154·0	6·12	4498
7	176·0	15·72	18·80	1·0351	10·0	166·0	6·07	4699
8	194·0	16·67	19·15	1·0262	11·5	182·5	5·89	5012
9	210·0	17·61	20·30	0·9988	12·6	197·4	5·75	5458

(2) The curve has minimum and maximum positions for $f/2$, between which positions a rising portion of the curve is in existence. The spread of the points around this rising portion—*i.e.*, between 2200 and 3000 R_e—is greater than the spread in the viscous region for the same system. Thus the reliability of any single determination is not great in the critical region. Yet, on the whole, the second run connects to the first run fairly well, despite the fact that the apparatus was partly dismantled in between the runs (to change the position of the constant-level device) and allowed to carry water for some days. Thus it may be concluded that, provided special precautions are taken to ensure constancy of inlet level, the viscous and turbulent regions may be connected by a curve showing minimum

and maximum values for $f/2$. The shape of such curve, however, is not a symmetrical **S**-shape.

(3) Comparing Fig. 4 with Fig. 1, it is noted that the position of the present curve corresponds to that of a galvanized tube slightly greater than $\frac{1}{2}$ in. in diameter. This fact is important, as the diameter of the present tube is only 0·161 in., and on the scheme presented in Fig. 1 the curve should have been above that occupying the highest position. Of course, the fact that the present tube was of drawn copper means that it was a "smooth" tube, and this explains the anomalous position when compared with galvanized tubes—which are assumed to be "rough"

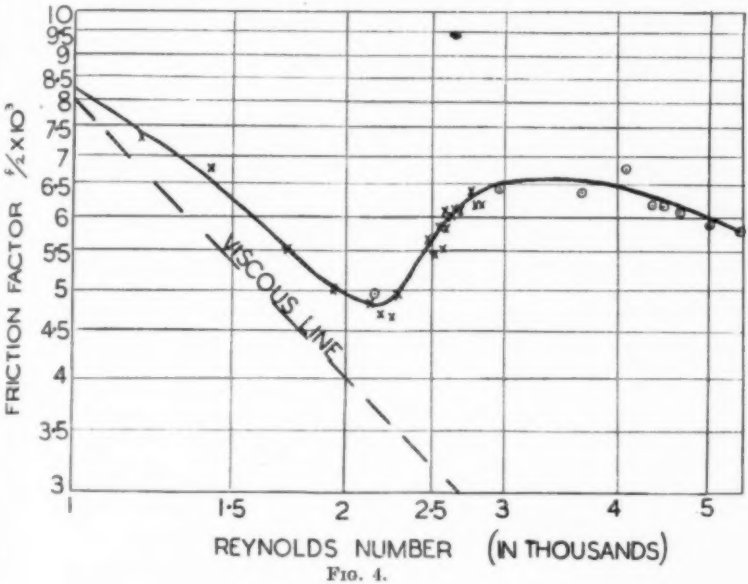

FIG. 4.

compared with copper. Nevertheless, it illustrates the fact that an extremely large error is possible if curves are taken from the literature haphazardly, without extreme care being shown with regard to the nature of the surface of the pipe. It is to be recommended that "spot tests" be made with any particular systems to locate it on the chart shown in Fig. 1. This is an important limitation of the $f/2$ *vs.* *Re* chart. The number of points required is discussed below. Taking the diameter alone as a criterion of roughness is evidently erroneous—except, of course, in such well-authenticated cases as the Weymouth's Formula for the flow of gases under high pressure and at the very high Reynolds numbers used in commercial transportation of natural gas.

(4) The shape of the curve shown in Fig. 4, coupled with the points discussed immediately above, make it appear that the best method of determining $f/2$ for the critical regime is to follow experimental procedure,

and not rely on mathematical formulation. The attempts at mathematical derivation of the incidence and significance of the critical region may be studied in Lamb's *Hydrodynamics*, to illustrate the extreme difficulties met in the problem.

It is pertinent here to inquire into the implicit significance and limitations of dimensional analysis on which a correlation such as that existing between $f/2$ and Re is based. The first point to remember is that despite the term " analysis " the method is purely an empirical one, based on certain experimental observations. Thus, in deriving the possible nature of the relationship between $f/2$ and the different variables affecting it, *it is assumed* that the *only* factors of significance are the velocity of flow, the diameter of the pipe, and the kinematic viscosity of the fluid. By taking these as the only factors and following certain standard procedure in equating dimensions, it is found that, if the assumptions are true, then $f/2 = \phi\ (R_e)$. This means that if no other factor is of significance in the problem, then a smooth repeatable curve will be obtained on plotting $f/2$ against the dimensionless criterion R_e. Two points are to be remembered : (1) If, besides the present factors, another is assumed to affect the value of $f/2$ under any one set of conditions, then a different type of criterion is obtained. (2) If a significant factor is ignored, then, although the analysis denotes that a relationship between $f/2$ and R_e should exist—*i.e.*, a smooth curve should result from plotting $f/2$ *vs.* R_e—in fact it will be found that either no curve is obtainable, or the experimentally found points will reveal a " spread " around the curve.

Thus, the relationship between $f/2$ and R_e can only be accepted if a smooth curve, with no appreciable spread of the points, is actually obtained by experiment.

The work of many has shown that, provided certain precautions are taken, such a curve is obtainable in the viscous region. This work shows that the precautions taken were sufficient, within the accuracy required in engineering calculations rather than viscometric studies, to produce a smooth curve if such exists—as in the viscous region. Yet in the critical region, the spread is much greater than that characterizing the viscous region. For instance, at Re of 2550, $f/2$ yields values ranging between 0·00552 and 0·00608. Thus it can only be concluded that whilst for the viscous region $f/2$ is wholly governed by R_e, in the critical region other factors not considered in the criterion R_e are operating.

An attempt was made to find whether surface tension was such a factor. By applying Buckingham's π-Theorem,[2] Weber's Criterion is obtained,

i.e., $$W_e = \frac{\sigma}{dv^2\rho}$$

where σ = surface tension.

d, v, and ρ = diameter, velocity and density as before.

Thus by plotting $f/2$ *vs.* W_e and various combinations of R_e and W_e, it was hoped to obtain a curve on which the experimental points will lie smoothly and without the spread, characteristic of the critical curve of $f/2$ *vs.* R_e. None of these attempts, however, resulted in such a curve.

Again, looking at the problem purely from a mathematical viewpoint,

and ignoring the physical significance of the various terms, it is found that a plot of $f/2$ *vs.* R_e is in reality a plot of $\frac{Hd^5}{Q_t^2\rho}$ *vs.* $\frac{Q_t}{\nu d}$. In a single system it reduces to a plot of $\frac{H}{Q_t^2}$ *vs.* $\frac{Q_t}{\nu}$. Such a plot is characterized by an

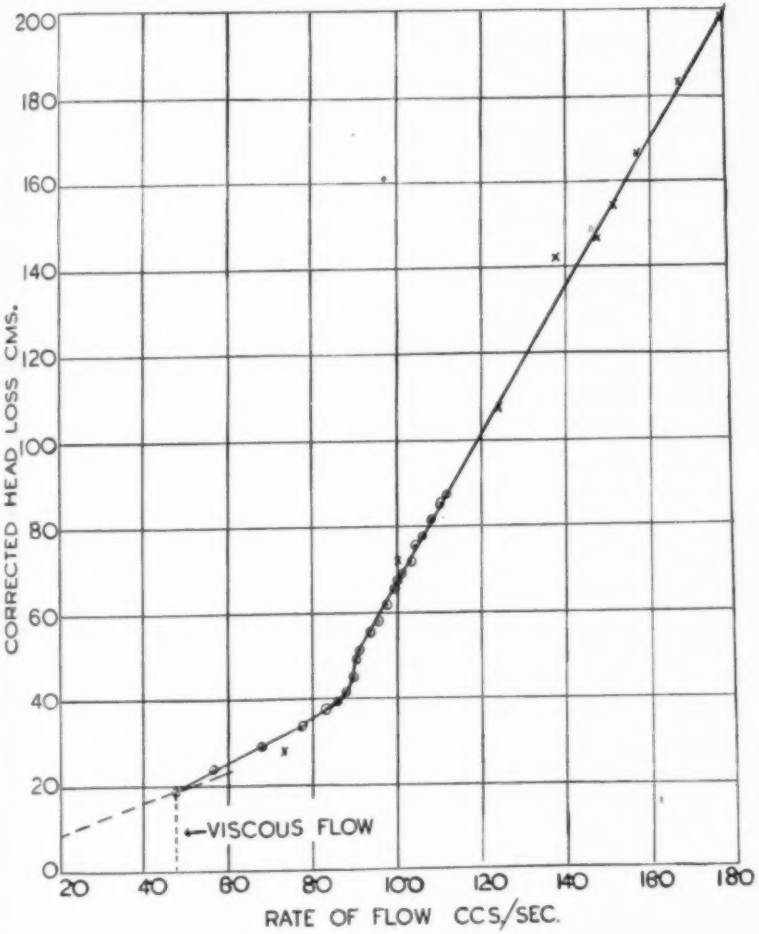

FIG. 5.

exaggerated spread of point for slight inaccuracies in Q_t.[3] In fact it is an extremely sensitive test of the accuracy of experimental data.

After it was seen that the significance of the Reynolds number in the critical region lies merely in its denoting the fact that such a regime has

been established, and, further, that the Reynolds number is not the sole governing criterion in such a region, it became necessary to find whether a simpler method of plotting the results is obtainable or not. Since plotting $\frac{H}{Q_t^2}$ *vs.* $\frac{Q_t}{\nu}$ exaggerates the spread of the points, it was thought that simpler plots may be obtained with H *vs.* Q_t. The factor due to viscosity was omitted, as it is known that in the turbulent region viscosity merely determines the type of flow taking place, and is of little direct importance in evaluating H. Fig. 5 shows that although the viscosity of the water varied between 0·0099 and 0·0124 stokes, it shows no influence on the curve.

It is also seen that a plot of H *vs.* Q_t in the critical region results in two accurately straight lines connected by a small region represented by an almost vertical straight line around the values of 2200–2500 R_e. The lower straight line differs slightly in slope from the line denoting viscous flow, and differs considerably from the upper line. It is important to realize that between Reynolds numbers 1000 and 2200 and between 2500 and 5000 the plot of the corrected head lost in the pipe *vs.* the quantity delivered is represented by straight lines on Cartesian co-ordinates. This means that the number of points to be determined experimentally in order to determine the characteristic flow curve for a system in the critical regime need not exceed 5–2 points between 1000 and 2000 R_e and 2 points between, say, 3000 and 5000 and a fifth determination around 2000–3000 to locate the vertical section of the curve. To determine the $f/2$ *vs.* R_e curve directly a considerable number of points is required, since the curve possesses both a maximum and a minimum. By means of this simplified plot, however, the five points are sufficient to calculate the whole range of $f/2$ *vs.* R_e curve. It is to be noted that Reynolds criteria still play their part in denoting the regime of flow and the relative position of the points in such a regime.

Another important significance of the plot of H *vs.* Q_t directly is that throughout the range covered by R_e of 1000–5000 the frictional resistance is directly proportional to the first power of the velocity according to the generalized equation :—

$$H = a + bQ_t$$

or

$$H = p + qv.$$

The constants, however, change their values between the range 1000 to 5000, as is seen by the graph. A plot of H *vs.* Q_t or v on logarithmic graphs would suggest the equation

$$H = mv^n.$$

This equation has, in fact, been proposed with an apparently varying exponent changing from 1 at a Reynolds number of 1000 to a value greater than 3 at values of R_e of 2500, and coming down to 1·6 at higher R_e values, only to rise again to nearly 2.[4] This complicated arrangement is due to the fact that on a logarithmic plot the independent constants (a or p) are included in the arbitrary constant m and the variable index n. The complication merely illustrates the disadvantages of indiscriminate use of logarithmic scales in flow problems.

Plotted on Cartesian co-ordinates the critical regime reveals the characteristic of viscous flow in that the head is proportional to the first power of velocity, but departs from viscous flow in that the plot does not pass through the origin, the straight line changes slope at certain points, and in that kinematic viscosity changes up to 25 per cent. appear to be insignificant.

In all model experiments it is important that every circumstance obtain-

TABLE III.

No.	H, cm. of water.	Q_t, c.c./sec.	t, ° C.	ν, centistokes.	Corrn. to H, $= 0{\cdot}0418\,Q_t^2$.	H corrd., cm. of water.	$f/2\times10^3$.	R_c.
1	21·36	5·251	9·39	1·332	0·68	20·68	6·94	1225
2	31·65	7·143	9·30	1·331	1·26	30·39	5·54	1668
3	42·90	9·091	8·84	1·334	2·05	40·85	4·56	2120
4	49·40	9·770	8·71	1·353	2·37	47·03	4·54	2243
5	59·60	10·50	8·42	1·358	2·74	56·86	4·75	2400
6	71·40	10·93	8·35	1·369	2·96	68·44	5·30	2480
7	84·20	11·65	8·30	1·372	3·37	70·83	4·82	2635
8	101·4	12·75	8·22	1·374	4·03	97·37	5·54	2884
9	118·4	13·91	8·14	1·377	4·80	113·60	5·42	3140
10	141·5	15·27	8·08	1·380	5·79	135·71	5·36	3440
11	161·5	16·34	8·85	1·383	6·61	154·89	5·36	3680
12	175·6	17·06	8·25	1·352	7·21	168·39	3·35	3930
13	193·3	18·10	7·80	1·376	8·13	185·17	5·22	4080
14	218·0	19·69	7·80	1·395	9·60	208·40	4·99	4390
15	260·0	21·50	7·80	1·395	11·48	248·52	4·97	4790
16	286·8	22·68	7·50	1·395	12·75	274·05	4·92	5050
17	337·9	24·60	7·40	1·407	15·00	322·90	4·92	5430
18	369·9	26·02	7·40	1·411	16·80	353·10	4·82	5730
19	396·0	27·13	7·40	1·411	18·23	377·77	4·74	5970
1	22·23	4·95	5·7	1·487	0·61	21·62	8·13	1034
2	25·91	5·62	5·9	1·478	0·79	25·12	7·32	1183
3	26·19	5·65	5·8	1·482	0·80	25·39	7·31	1183
4	30·86	6·51	5·8	1·482	1·10	29·76	6·48	1360
5	30·91	6·52	5·9	1·478	1·12	29·79	6·47	1370
6	35·66	7·78	5·9	1·478	1·50	34·16	5·23	1634
7	35·76	7·46	5·8	1·482	1·38	34·38	5·69	1563
8	41·16	8·31	5·8	1·482	1·72	39·44	5·28	1740
9	45·26	9·00	5·7	1·487	2·01	43·25	4·93	1879
10	45·76	9·16	5·9	1·478	2·09	43·67	4·81	1926
11	48·86	9·48	5·8	1·482	2·23	46·63	4·77	1985
12	51·81	9·90	5·9	1·478	2·44	49·37	4·73	2081
13	55·26	10·16	5·9	1·478	2·56	52·70	4·71	2137
14	58·36	10·57	5·8	1·482	2·78	55·58	4·58	2215
15	58·96	10·59	5·9	1·478	2·79	56·17	4·61	2224
16	64·31	11·05	5·9	1·478	3·03	61·28	4·62	2327
17	65·36	10·96	5·6	1·491	2·98	62·38	4·79	2283
18	72·96	11·40	5·5	1·496	3·23	69·73	4·94	2370
19	78·46	11·68	5·5	1·496	3·39	75·07	5·07	2423
20	85·06	12·41	5·5	1·496	3·84	81·22	4·85	2578
21	107·3	13·51	6·2	1·466	4·55	102·7	5·17	2864
22	120·0	14·12	6·2	1·464	4·94	115·1	5·32	2963
23	143·3	15·62	6·2	1·464	6·06	137·2	5·09	3311
24	169·4	16·93	6·3	1·460	7·12	162·3	5·18	3634
25	199·5	18·59	6·3	1·460	8·60	190·9	5·08	3955
26	212·8	19·3	6·4	1·455	9·25	203·5	5·03	4111
27	454·0	29·0	6·5	1·451	20·85	433·1	4·75	6212
28	478·0	29·4	7·1	1·421	21·5	456·5	4·86	6430

ing in the large-scale apparatus should be copied in the model. In these experiments it was stressed that extreme precautions were taken to ensure that the inlet pressure was maintained constant. In actual practice such precautions are usually impracticable. Thus it is interesting to see the effects of slight oscillation produced at random, and not by any predetermined system, on the curves obtained.

The following results were obtained by using a single constant-level device on the inlet, which maintained the inlet level constant to the limits of reading the manometric scales, throughout the viscous region. The extra velocity required in the critical region produced a slight oscillation in the inlet level as the water entered the constant-level device from the

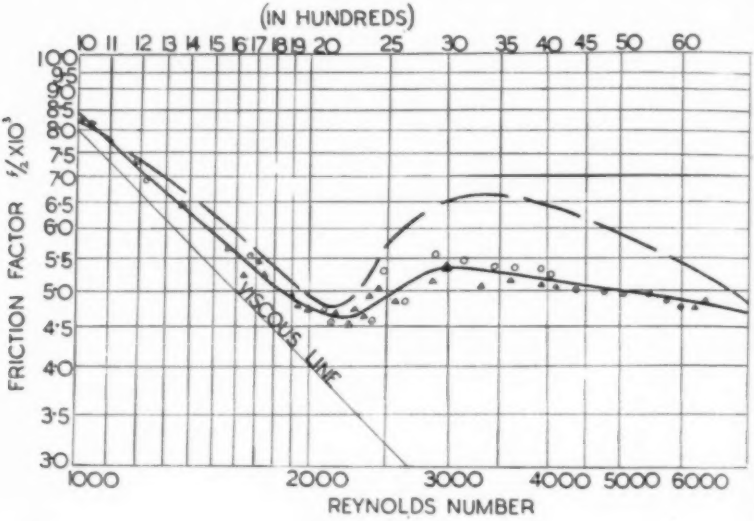

FIG. 6.

tap. This oscillation, coupled with that due to the regime itself, resulted in variation in the inlet pressure comparable with what might obtain in a technical apparatus being fed by a pump having small pulsation. The results obtained in these tests are shown in Table 3.

In Fig. 6 is a plot of $f/2$ *vs.* R_e for this set of experiments. Certain interesting facts become evident on comparing this curve with that obtained in Fig. 4, shown broken on Fig. 6.

Up to a Reynolds number of 2100–2200, the two curves are practically the same. Beyond 2200, however, the two curves become distinctly different. The curve where shocks were not eliminated shows :

(1) a low value for $f/2$ for any value of R_e between 2100 and 6500;

(2) a greater amount of "spread"—*i.e.*, is less reliable than the curve of Fig. 4. At higher values of R_e the two curves apparently coincide.

Thus in model experiments care should be exercised that no extra precaution be taken than is practicable in the final apparatus. In other words, discretion should be exercised in choosing a value for $f/2$ from the literature, not only with regard to roughness, diameter, nature of surface, etc., but also with regard to the actual technique used and precautions taken. In these last sets of results the readings were taken as accurately

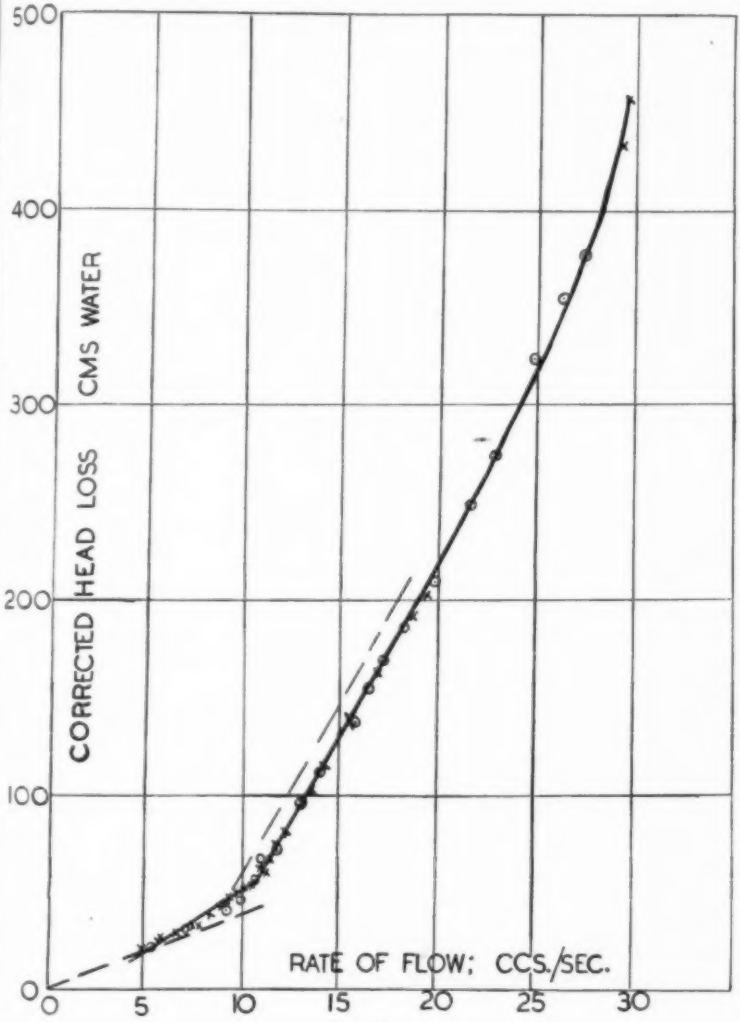

FIG. 7.

as in those previously reported, and all conditions were maintained the same save the random fluctuations in the head. These fluctuations never exceeded 3 mm. water. In each case time was allowed for a steady state to be established.

Finally, Fig. 7 presents results of practical interest and importance. It is a plot of the head lost in frictional resistance against volumetric rate of flow, neglecting a 15 per cent. overall change in kinematic viscosity. It is similar to Fig. 5 in two respects and different from it in two others. For the range of R_e between 1000 and 2100 approximately it yields a straight line identical with that obtained when pulsation at inlet was eliminated. Also similarly to those tests, a straight line connects points obtained between 3000 and 5000 R_e. These two straight lines obtained in the circumstances mentioned are not, however, identical, as can be seen in Fig. 7, where the dashed line represents the previous results. They are almost parallel, with the present line lying below the previous one. This constitutes the first difference. The second major difference is the absence of the vertical section of the curve connecting the lower straight line with the upper one seen in Fig. 5. Here the two straight lines merely intersect. Thus it is concluded that the vertical section of the curve in Fig. 5 represents an unstable state which can only be realized in laboratory experiments where special precautions are taken to preserve it. In ordinary practice it disappears.

Above 5000 R_e the plot of corrected head loss *vs.* volumetric rate of flow follows the normal curved line characteristic of the turbulent regime.

Conclusions.

(1) In laboratory experiments where special precautions are taken to eliminate all pulsations at the inlet to the system, a plot of log $(f/2)$ *vs.* log (R_e) yields an asymmetrical S-shaped curve within the region of 1000-5000 R_e.

(2) The limb of this curve, between 1000 and 2200 R_e, is not identical with the extrapolated curve of streamline flow. It lies above it.

(3) This curve, obtained for a copper tube 0·161 in. in diameter, lies in a region on the general chart shown in Fig. 1 corresponding to a galvanized tube of slightly greater diameter than 0·5 in.

(4) For such experiments a plot of frictional head *vs.* rate of flow yields a straight line for the region of 1000–2200 R_e, another straight line for the region of 2500 and 5000 R_e, and a vertical line connecting the two straight lines. A change of 25 per cent. in viscosity may be ignored. Both straight lines have different slopes from each other and from the viscous line.

(5) Where pulsations in the inlet are not eliminated, a plot of log $(f/2)$ *vs.* log (R_e) yields an asymmetrical S-shaped curve within the range 1000-5000 R_e. This curve is not identical in all parts with the similar curve obtained where pulsations were eliminated.

(6) The limb of this curve, between 1000 and 2200 R_e, is almost identical with the corresponding part of the curve obtained when pulsations were eliminated.

(7) A plot of the frictional head *vs.* rate of flow for these experiments

(where pulsation in the inlet was present) yields two straight lines intersecting at an approximate value of 2400 R_e and covering the region between 1000 and 5000 R_c. Above 5000 R_e the plot is a curve characteristic of the turbulent region. There is no apparent unstable region connecting the two straight lines. The straight line covering the region 1000–2400 R_e is identical with that obtained in experiments where pulsations were eliminated. The line connecting 2400–2500 R_e to 5000 R_e is parallel to the corresponding line, obtained where pulsations have been eliminated, but is lower in H values on the chart. Viscosity change of 15 per cent. has been ignored with no apparent effects.

(8) In technical apparatus where pulsations are not eliminated the head lost in the critical region is proportional to the first power of the rate of flow, with the constant of proportionality assuming a value in the region 1000–2400 R_e slightly greater than the value for the viscous regime, and assuming a still greater, but constant value, between 2400 and 5000 R_c. Thus the critical regime is similar to the viscous regime in having linear relationships between frictional head and rate of flow, and it is similar to turbulent flow in the small direct influence that viscosity appears to have.

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[1] Beale, E. S. L., and Docksey, P., "Science of Petroleum." Oxford University Press, 1938, p. 718.
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[3] Sherwood, T. K., and Reed, C. E., "Applied Mathematics in Chemical Engineering." McGraw-Hill Book Co., Inc., 1939, p. 298.
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GRAPHICAL AND MECHANICAL DETERMINATION OF THE TRUE DIP FROM MAGNETICALLY ORIENTATABLE CORES TAKEN IN CROOKED HOLES.*

By Dr. G. D. Hobson.

Several years ago Lynton [2] described apparatus for the orientation of well-cores according to their magnetic polarity. In vertical holes the satisfactory orientation of cores in this manner makes possible the measurement of the true dip and dip direction of the beds at the point of coring, assuming that the earth's magnetic field at the point of coring is in the same azimuth as at the surface. Cores taken in crooked holes and then orientated magnetically when the core is vertical merely show an apparent dip and dip direction. The inclination of such cores to coincide with the deviation of the hole gives the true dip and dip direction of the beds only when, at the same time, the direction of magnetization of the core is made to agree with the earth's magnetic field.

At the end of his paper Lynton described a mechanical deviation corrector for finding the true dip and dip direction of the beds from magnetically orientatable cores cut in crooked holes. In this device the plane of a board pivoted on the upper end of a vertical rod is set to show the apparent dip and dip direction of the bedding in the core when a horizontal pointer attached to the rod is pointing east–west. The rod, with attached pointer and tilted board, is next inclined at an angle and in a direction corresponding with the deviation of the borehole. If this movement has deflected the pointer out of a vertical east–west plane, the rod is rotated about its longitudinal axis until the pointer lies once more in a vertical east–west plane. The last adjustment is assumed to bring the board into a position in which its plane gives the true dip and dip direction of the beds. In most instances this assumption is incorrect, although the error involved may be small provided that the deviation of the well from the vertical is not large. The error arises from the fact that the final rotation about the rod's longitudinal axis does not restore the magnetic lines of force in the core to their proper direction, except in a few cases. Consequently, the plane representing the dip of the beds is not always correctly set in space.

Johnson [1] noted the seat of the error without stating specifically that the recommended method of using Lynton's mechanical deviation corrector is not flawless. He outlined a series of steps which would give the true dip and dip direction from magnetically orientated cores, but his discussion is not really clear on all points. He also described a stereographic net solution of the problem, and worked out three examples, the basic data for which were not presented in a manner calculated to make easy the understanding of the method employed.

It would appear that the apparent dip and dip direction of the core bedding, coupled with the deviation of the hole, do not, in general, provide

* Received 4th September, 1942.

sufficient data for determining accurately the true dip and dip direction of the beds. Either the actual direction of the lines of magnetic force in the core or the dip of the earth's magnetic field must also be known. A knowledge of the dip of the earth's magnetic field seems to be most convenient, although it will usually involve the assumption that the dip of the lines of force at the surface, where the dip is most easily measured, is the same as at the point in the earth's crust at which the core was taken. Johnson's stereographic net solution employs the deviation of the hole, the dip of the earth's magnetic field, and the apparent dip and dip direction of the bedding in the magnetically orientated core. If necessary the same data may be used to solve the problem graphically without any special device, although the graphical solution is not so quick as the stereographic net solution.

Consider a core as it lies in the bed from which it is cut in a crooked hole, and focus attention on the true dip and dip direction of the beds, the direction of the earth's magnetic field and the axis of the well—*i.e.*, the axis of the core. The axis of the core can be made vertical by rotating the core about a horizontal line lying in a plane perpendicular to the axis of the well. The angle of rotation is equal to the deviation of the well from the vertical. In most instances the rotation will swing the lines of force within the magnetic core out of the vertical planes containing the earth's lines of force, and it will also change the direction and amount of dip of the beds. Rotation of the core about its axis, now vertical, allows the core's lines of magnetic force to be brought back into the vertical planes containing the earth's lines of force, although the two sets of lines of force will not necessarily dip at the same angle. The apparent dip and dip direction of the bedding in the core may be measured in this position, and the measurements will agree with those obtained on cores, the north and south sides of which have been determined by means of Herrick and Lynton's apparatus.[2]

The graphical solution mentioned above is based on a reversal of the series of movements described in the preceding paragraph, and is as follows :—

Let the dip of the earth's magnetic field be δ; the apparent dip of the beds in the magnetically orientated core α in a direction θ, measured clockwise from magnetic north; and the deviation of the well β from the vertical in a direction ϕ, again measured clockwise from magnetic north.

Set out a line representing magnetic north–south (Fig. 1) and mark a point O near its middle.* From O mark off to the north† a distance OX of length $\frac{100}{\tan \delta}$ cm.‡ to scale.

The strike of a plane perpendicular to the axis of the deviated hole is

* This graphical solution involves the use of a plan and elevation. The point on the elevation corresponding with a point on the plan is given the same letter with a suffix $_E$. The point to which a given point moves as a result of any of the movements described, is given the same letter with a suffix $'$.

† In Fig. 1 it is assumed that the magnetic lines of force dip downwards to the north. The method is still applicable even though the dip may not be downwards to the north. The procedure needed to meet this second case will be apparent since the method aims at depicting the actual movements necessary to set the core in its correct position in space.

‡ The choice of 100 cm. as the depth unit is purely arbitrary. Any other unit will serve so long as it is used throughout.

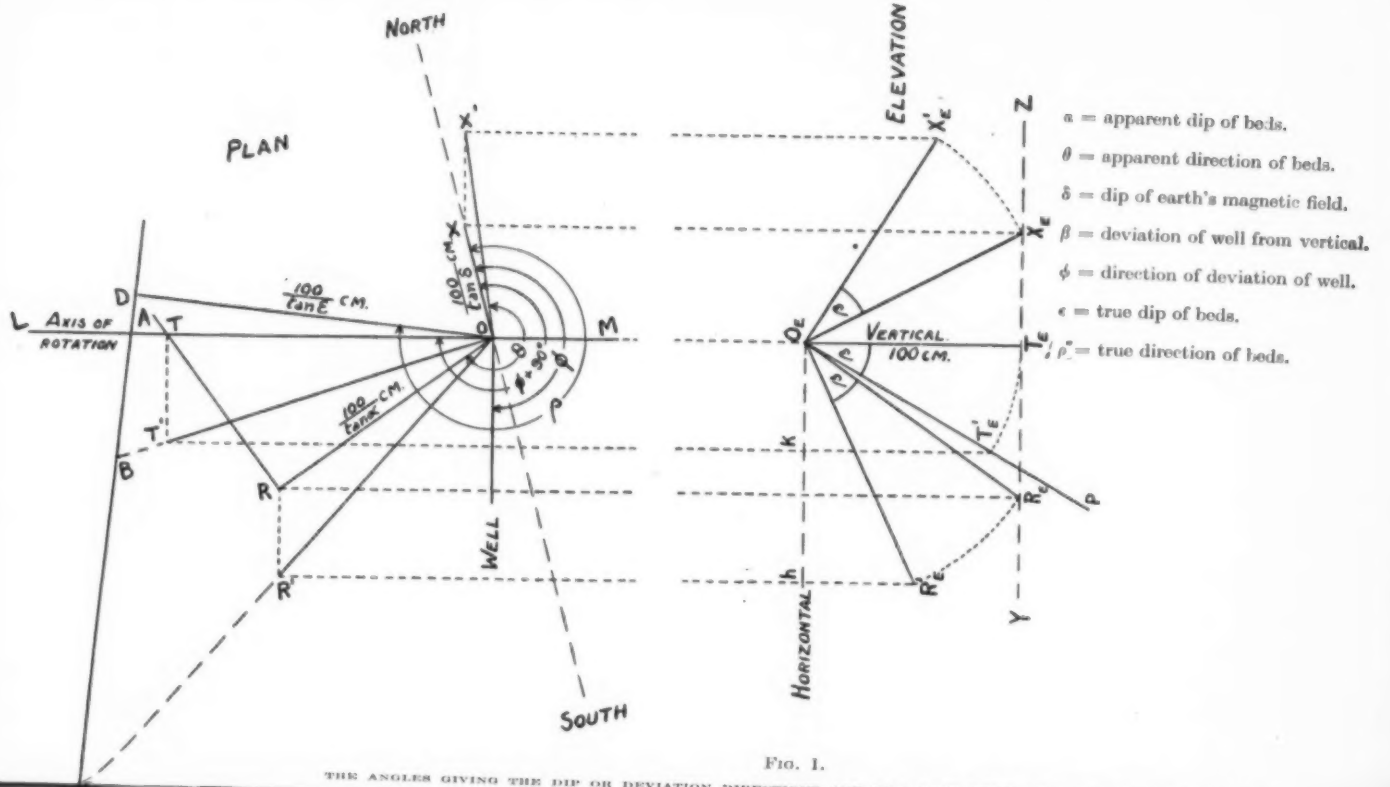

FIG. 1.

THE ANGLES GIVING THE DIP OR DEVIATION DIRECTIONS ARE RECORDED FROM MAGNETIC NORTH AS ZERO.

$\phi + 90°$, and the plane dips at an angle β in the direction $\phi + 180°$. Through O draw a strike line LM running in the direction $\phi + 90°$. Produce LM, and on the extension mark a point O_E which is to be considered as the position on the elevation corresponding with O on the plan, the elevation being drawn when looking in the direction ML. Vertically below O_E on the elevation—*i.e.*, on the extension of LM—mark a point T_E, 100 cm. below O_E, and at right angles to $O_E T_E$, draw a straight line $YT_E Z$, which will be the representation of a horizontal line. From X drop a perpendicular XX_E on to YZ, thus locating the position on the elevation corresponding with X on the plan, for OX on the plan is the horizontal projection of a line of force which is supposed to run north from O until it meets a horizontal plane 100 cm. below O. On the elevation the axis of the well may be represented by a line $O_E P$ making an angle of β with $O_E T_E$. In order to make the well vertical, there must be rotation about the axis LM, which means rotation about O_E on the elevation. Applying rotation through an angle β about O_E will cause X_E to move to X'_E, where $O_E X'_E = O_E X_E$, and $\angle X'_E O_E X_E = \beta$. On the plan, rotation about LM will cause the plan positions of all points not actually on LM to be displaced in directions at right angles to LM. Hence, X will move to X', where X' is fixed by the intersection of a line at right-angles to LM through X, and a line at right-angles to YZ through X'_E.

The rotation described in the previous paragraph has swung the earth's magnetic field into the plan direction OX'. If the vertical core is turned about its axis until its magnetization has the plan direction OX', it will be correctly related to the beds from which it was cut, and later rotation through an angle β about the axis LM will restore it to its original orientation in space.

From OX' measure an angle θ in a clockwise direction and draw OR, which is $\frac{100}{\tan \alpha}$ cm. long, to show the apparent dip and dip direction of the core bedding when the core's magnetic lines of force have been made parallel to the magnetization of the beds from which the core was cut. On the elevation R_E is the point corresponding with R on the plan. Tilting the core through an angle β about the axis LM, in order to give it its correct position, causes R_E to move to R'_E by rotation through an angle β about O_E. $O_E R_E = O_E R'_E$ and $\angle R'_E O_E R_E = \beta$. On the plan the position of R after the rotation is R', which is located from R and R'_E just as X' was located from X and X'_E. The depth of R' below O is hR'_E, where hR'_E is measured at right angles to a horizontal line through O_E on the elevation.

The two points O and R' are not sufficient to determine the true dip and dip direction of the beds, and so a third point must be used. Since OR is drawn as an apparent dip direction, a line RA at right angles to OR gives the plan positions of a series of points which are 100 cm. below O and in the plane of apparent dip of the core bedding when the core is vertical. Any point on the line RA is suitable provided that it is not too near to R. Alternatively, a point on a line parallel to RA through O may be selected. In this case the point will be at the same level as O, since it will be on a horizontal line in the plane of apparent dip of the beds. In the present example T, the point on the plan intersection of RA and LM, has been

FIG. 1.

THE ANGLES GIVING THE DIP OR DEVIATION DIRECTIONS ARE RECORDED FROM MAGNETIC NORTH AS ZERO.

chosen, and this is represented on the elevation by T_E, 100 cm. (to scale) below O_E. On rotation through an angle β about the axis LM (*i.e.*, about O_E), T_E moves to T'_E, and the new plan position of T is T', located in the same way as X' and R'. $O'_E T'_E = O_E T_E$ and $\angle T_E O_E T'_E = \beta$. The

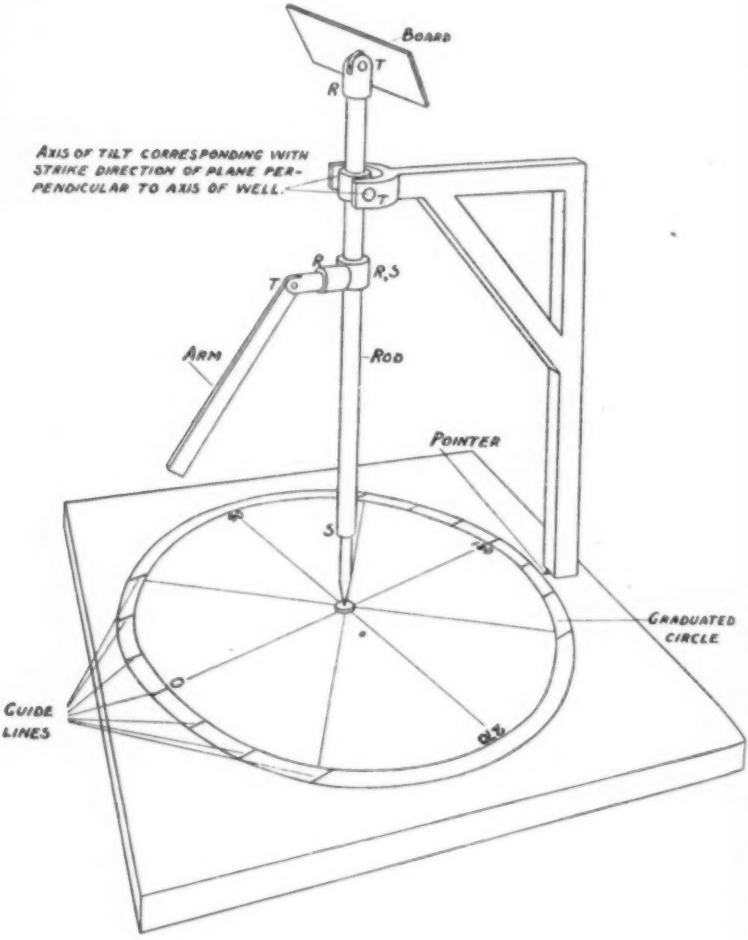

FIG. 2.

SUGGESTED FORM OF DEVIATION CORRECTOR FOR USE WITH MAGNETICALLY ORIENTATED CORES.

T = axis of tilt; R = sleeve allowing rotation; S = sleeve allowing sliding; R, S = sleeve allowing rotation and sliding.

The concentric circles within the graduated circle have been omitted in this sketch.

depth of T' below O is kT'_E, where kT'_E is measured at right angles to a horizontal line through O_E.

From the depths and plan positions of R', T', and O, the true dip and dip direction of the beds may now be determined. By simple proportion a point B is selected on OT' or OT' produced, such that it is 100 cm. below O ($OB = OT' \cdot \frac{O_E T_E}{kT'_E}$). Similarly, a point C is selected on OR' or OR' produced, such that it also is 100 cm. below O ($OC = OR' \cdot \frac{O_E T_E}{kR'_E}$). The straight line joining B to C is the true strike of the beds. A perpendicular OD, from O on to CB or CB produced, is therefore the true dip direction, and the length of OD is $\frac{100}{\tan \varepsilon}$ cm. to scale, ε being the true angle of dip of the beds. The value of ε may be found graphically or computed from the length of OD.

Lynton's deviation corrector can be modified so that it will give the true dip and dip direction of the beds in magnetically orientated cores. Fig. 2 shows the essential features of the modification. A vertical rod is pivoted on a horizontal axis which is considered to be the strike direction of a plane normal to the axis of the well. On the top end of the rod is mounted a board which can be tilted or rotated relative to the rod. The plane of the board is used to define the bedding planes of the formations. There is a slider on the rod below the axis of tilt of the rod. The slider carries a short arm which can be rotated about its own axis and has a pivoted arm on its end. This arm can be set to show the angle of dip of the earth's magnetic field. Centred below the rod when the rod is vertical is a graduated disc which may be rotated about its centre. In addition to being graduated circularly in degrees, the disc has a series of concentric circles of such radii that when the pointed extensible tip of the rod is set on one of them, the tangent of the angle of deviation of the rod from the vertical is given by dividing the radius of the circle by the height of the axis of tilt of the rod above the centre of the circle. The angle of deviation is marked on the circles. The direction of deviation of the well is shown by a pointer on the base board of the apparatus. A series of short guide-lines parallel to the north–south direction on the graduated circle are marked on the edge of the disc.

An additional piece of apparatus is required which takes the form of a protractor screwed flat on to a vertical board. This board, with its plane adjusted to a north–south direction by means of the north–south guide-lines, may be set close to the pivoted arm. The inclination of the arm can then be made equal to the angle of dip of the earth's magnetic field. The board also facilitates the determination of the direction of dip of the arm in the later stages of the process of finding the true dip of the beds.

All the joints on this deviation corrector must be fairly stiff, whether they allow sliding or rotation, and set-screws may be required to maintain them in the positions in which they are set.

Briefly, the method of using the deviation corrector will be as follows :—

(1) Rotate the graduated circle until the angle giving the direction (magnetic) of deviation of the well is opposite the pointer.

(2) Incline the rod to agree with the angle of deviation of the well by setting its point on the appropriate circle.

(3) Set the arm in a vertical north–south plane (magnetic) at the angle of dip of the earth's magnetic field by means of the protractor fixed on the vertical board.

(4) Move the rod into a vertical position and note the direction of the vertical plane in which lies the arm set to show the dip of the earth's magnetic field. Counting this direction as north–south (magnetic), adjust the board at the top of the rod until it agrees with the apparent dip and dip direction of the bedding in the magnetically orientated core. A compass and clinometer may be used for this adjustment.

(5) Incline the rod once more until it shows the same angular deviation from the vertical as the well.

(6) Measure the angle of dip of the board and its dip direction relative to the north point on the graduated circle. The angles obtained are the true dip and dip direction (magnetic) of the beds.

References.

[1] Johnson, C. H., *Bull. Amer. Ass. Petr. Geol.*, 1939, **23** (5), 663.
[2] Lynton, E. D., *Bull. Amer. Ass. Petr. Geol.*, 1937, **21** (5), 580.

THE PARLIAMENTARY AND SCIENTIFIC COMMITTEE.

THE Parliamentary and Scientific Committee, of which the Institute of Petroleum is a constituent organization, has been deeply concerned during recent months with the important problem of the more effective use of scientists and technologists in the war effort. After lengthy and thorough discussion of the problem, the Committee decided that the supreme desideratum was the early establishment of a full-time Central Scientific and Technical Board to co-ordinate scientific and technical research and developments in relation to the war effort. As a first step, a distinguished and influential deputation waited on Mr. R. A. Butler, M.P., to urge the acceptance of the proposal by the Government. The next step was the tabling of the following motion on the Order Papers of the House of Commons :—

> "That this House is of the opinion that present circumstances require the early establishment of a whole time Central Scientific and Technical Board to co-ordinate research and developments in relation to the war effort and to ensure that the experience, knowledge and creative genius of British Technicians and Scientists exert a more effective influence over the conduct of a highly mechanised war."

The motion was supported by 126 members of the House of Commons, but before it could be debated in the House, the Government appointed three full-time scientific advisers and issued the following explanatory statement :—

> "The field of activity of these advisers will be co-extensive with the responsibility of the Minister of Production. They will keep in close touch with the scientific advisers of the Service and Supply Departments, and will be available to assist the departmental organizations of scientific research and technical development. They will not supersede the departmental organizations, which will, for instance, continue to be responsibile for the examination of new inventions and technical suggestions in their own fields.
>
> "They will be responsible to the Minister of Production, but will work under the immediate supervision of the Lord Privy Seal, acting on his behalf.
>
> "These appointments have been made with a view to completing the existing organization for scientific research and development which has been carefully built up over a number of years and operated with outstanding efficiency.
>
> "The Government have reviewed the whole position in the light of recent representations, and have decided that the creation of the post of Minister of Production affords the opportunity for this further measure of co-ordination which the Government believe will be to the national advantage."

By making these appointments, the Government conceded part of the request for a full-time Scientific and Technical Board, but the failure to create such a Board and the consequent attempt to fit the appointments into the existing administrative machine, resulted in an arrangement that was somewhat confusing and baffling and open to criticism such as that exemplified by the following extract from a leading article in *The Times* on the subject.

> "The qualifications of the scientists selected are beyond question. What remains to be proved in practice is the use which can be made of their services in the conduct of war under the arrangement now announced.
>
> "On this point the portents are not wholly reassuring. What had been widely urged upon the Government was the association of an authoritative group of scientists not so much with the Ministry of Production—it must be presumed that Mr. Lyttelton has from the first enjoyed the assistance of scientific advisers—as with those responsible for the central direction of the war. It is therefore somewhat baffling to find that, though the three scientists now appointed will work "under the immediate supervision of the Lord Privy Seal", Sir Stafford Cripps will be acting in this capacity not on behalf of the Prime Minister or of the War Cabinet as a whole, but on behalf of the Minister of Production. This arrangement would, if pressed to its logical conclusion, appear to place a serious limitation on the scope of the functions which they are called on to fulfil."

The Parliamentary and Scientific Committee, after thorough discussion of the appointments, passed the following resolution which was published in the Press.

> "This committee, while welcoming the appointment of three full-time scientific advisers to the staff of the Ministry of Production in so far as it establishes the nucleus of a central scientific and technical board, regrets that their field of activity is apparently to be limited to the sphere of production and does not include the scientific and technical activities of the service Departments or the other Ministries outside the strict field of production. An extension of its functions is needed to ensure that all scientific considerations are co-ordinated and given full weight over the whole field of the national effort. The committee considers, therefore, that in order to cover this wider field, scientific advisers should have direct access to the War Cabinet and that accordingly the Lord Privy Seal should exercise his supervisory functions over the new body directly on behalf of the War Cabinet."

Dissatisfaction with the appointments was also expressed by the tabling of a number of questions on the Order Papers of the House of Commons, to which the Minister of Production replied in a statement which contained the following sentence.

> "Their advice and recommendations will normally be presented to me through the Lord Privy Seal; it will, of course, be for me to

bring their advice and recommendations to the notice of the War Cabinet as may be necessary."

This sentence would appear to be significant and important as it is the first mention of the provision of a definite link between the scientific advisers and the War Cabinet.

On the basis of the assumption that the appointment of a Central Scientific and Technical Board is not a feasible proposition at the present time, the arrangement that has been made is probably the best alternative and possesses many advantages. The three scientific advisers will work under the supervision of a member of the War Cabinet who took a scientific course at University College, London, was an assistant superintendent at an ordnance factory during the 1914–1918 war, and in his legal practice frequently demonstrated his rapid grasp of scientific facts and principles. Indeed, there could have been no better choice for this supervisory post. Moreover, the scientific advisers will be responsible to the member of the War Cabinet who is in close touch with the greatest number of Ministries, and who will bring scientific advice and recommendations to the notice of all who are responsible for the central direction of the war. It may also be found in practice that the scope of the functions of the scientific advisers is not so circumscribed as would appear from the formal announcement by Government, for as *The Times* states: "The appointments would be meaningless if the new advisers were not intended to survey the whole conduct of the war from the standpoint of science and, free from direct departmental responsibility, tender their general advice on scientific problems and scientific opportunities in whatever field that may arise." These considerations provide ample ground for the hope that the arrangement will prove to be so fruitful as rapidly to dispel existing misgivings regarding the establishment of a full-time Central Scientific and Technical Board. In any case, the three full-time scientific advisers may confidently be expected to render most valuable service in the war effort, and their appointment is a marked advance on the previous position and is a notable achievement of the Parliamentary and Scientific Committee.

T. DEWHURST.